1,032,095

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,032,095

Inventor:
DAVID CHARLES ARTHUR LEGGATT

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Improvements relating to gear wheels and racks.

COMPLETE SPECIFICATION

We, ASSOCIATED ELECTRICAL INDUSTRIES LIMITED, a British Company having its registered office at 33 Grosvenor Place, London, S.W.1., do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to improvements in gear wheels and racks, and more particularly to helical gear wheels and racks in which the profiles of the teeth are based on arcs of circles, and in which in use a convex surface on one tooth engages with a concave surface on a tooth of the complementary gear wheel or rack.

Gears of this form are often referred to as "NOVIKOV" gears. It will be appreciated that the radius of curvature of the concave surface must be at least as large as that of the convex surface. In the following description, the various radii of curvature are those of the teeth in sectional planes which are normal to the helix at that point.

The relative radius of curvature of conforming tooth profiles is given by

$$p_n = \frac{p_o \quad p_i}{p_o - p_i}$$

where p_o = concave flank radius
p_i = convex face radius.

The load carrying capacity of such a gear system is, according to the Hertzian theory of compressive stress, approximately proportional to p_n. Thus it is essential to have p_n as large as possible. Therefore both p_o and p_i should be large but the difference between them should be kept to a minimum.

The tolerance in the distance between the centres of the shafts carrying two such gear wheels is given by

$$\delta C = (p_o - p_i)(\sin \varphi_p - \sin \varphi_w)$$

where φ_p and φ_w are the limiting pressure angles for pinion and wheel respectively. From this it can be seen that allowable centre distance error is directly proportional to the difference in profile radii of curvature.

The criterion in the design of these gears is the centre distance tolerance. This is dictated by manufacturing accuracy of gears and gearbox and by service effects such as shaft deflections, thermal expansion and bearing play and wear. Thus the difference in radii of curvature is fixed and so to increase the load bearing capacity the only possibility is to make p_o and p_i as large as possible.

One of the conditions of contact for gear teeth is that, in order to produce a constant angular velocity ratio between the two mating gear wheels, or between the mating gear wheel and rack, the common surface normal at the point of contact of a pair of gear teeth must pass through a fixed point known as the pitch point. This is the point where the pitch circles of the two gear wheels touch. In the WILDHABER-NOVIKOV gear form this condition is not true for the whole length of the contacting teeth at any one time. The gears are helical and there is (theoretically) point contact which moves along the axial length of each tooth, but the condition applies instantaneously at the point of contact. In practice, due to elastic deformation of the tooth surface, a small ellipse of contact will exist.

Because the tooth profiles are arcs of circles, to ensure that the common surface normal passes through the pitch point, the centres of curvature of the profiles must be collinear with the pitch point at the instant of contact. Heretofore, it has been the practice to locate the centre of the concave curve on, or near the pitch cylinder, and to locate the centre of the convex curve on the same side of the pitch circle as the tip of the tooth bearing the convex curve, so that the centres are collinear with the pitch point at the instant of contact.

An object of the present invention is the

provision of a helical gear set in which the profiles of the teeth are based on arcs of circles, and in which the teeth have an increased load bearing capacity.

According to the invention, a helical gear set comprises complementary first and second gear members having gear teeth, the respective profiles of which are, at each transverse cross-section, convex and concave curves based on arcs of circles, wherein the centre of curvature of each convex curve at each transverse cross-section is located on the pitch surface of the first gear member, and the centre of curvature of each concave curve at each transverse cross section is located on the side of the pitch surface of the second gear member which is remote from the roots of the teeth of the second gear member, the radius of curvature of each convex curve being not less than the chordal thickness of the teeth of the first gear member.

In the above paragraph, and throughout the remainder of the specification, the term "chordal thickness" refers to the thickness at the pitch circle of convex faced teeth, and means the length of the chord subtended by the pitch circle arc which lies between the convex faces of the teeth.

The invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 is a sectional elevation, in a plane through the point of contact and normal to the helix, of part only of two mating helical gear wheels.

Figure 2 is a sectional elevation, in a plane through the point of contact and normal to the helix, of part only of a rack and a mating helical gear wheel.

Figure 3 is an enlarged sectional elevation of one of the teeth of the upper gear wheel of Figure 1 and of the two complementary teeth on the lower gear wheel.

Figure 4 is a sectional elevation, corresponding to Figure 3 of part only of a ring, or internally toothed, gear wheel and a mating helical gear wheel; and

Figure 5 is a sectional elevation of an alternative to the arrangement shown in Figure 4.

Referring first to Figures 1 and 3, the lower gear wheel 1 is provided about its periphery with teeth 2 the working parts 3 of which are arcs of circles. For each tooth, the centre of curvature 4 of the tooth face at each transverse cross-section lies at the intersection of the pitch circle and the opposite tooth face. This point is so chosen that, when load is being transmitted, it lies at the pitch point. The centre of curvature 8 of the working parts 9 of the teeth 10 of the upper wheel 11 is below the pitch point 13 where the pitch circle 15 of the upper gear wheel touches the pitch circle 7 of the lower wheel, i.e. is outside the pitch circle of the wheel on which the teeth are provided. The point of contact between the two teeth moves circumferentially along the profiles of both teeth as the tooth approaches the pitch point, and the centre of curvature 8 is suitably chosen to lie on the common normal to the surfaces at the point of contact, when the point 4 lies at the pitch point, where the pitch circle intersects the axis 5 joining the axes of the two gear wheels. As shown in Figure 3, the radius of curvature of the convex faces is equal to the chordal thickness T of teeth 2.

Referring now to Figure 2, the rack 21 is provided with teeth 22 which engage teeth 25 on a gear wheel 26. For a rack, the pitch line 28 is a straight line and the centres of curvature of the concave arcuate working parts of the teeth 22 lie below the pitch line 28 while the centres of curvature of the convex arcuate working parts of the teeth 25 lie on the pitch circle of the gear wheel 26.

It will be evident that for a given mismatch of the radii both p_o and p_i can be increased by the amount of the mismatch.

If p_o and p_i refer to the radii of curvature in the case where the centre of curvature of the concave tooth flank is at the pitch point, the mismatch equals (p_o-p_i).

If p_{oa} and p_{ia} refer to the adjusted radii of curvature in the case where the centre of curvature of the convex tooth face is at the pitch point, in accordance with the invention, the mismatch equals $(p_{oa} - p_{ia})$.

However, the amount of mismatch is limited to $(p_o - p_i)$ for considerations of centre distance tolerance. Therefore p_{oa} and p_{ia} are chosen so that

$$(p_{oa} - p_{ia}) = (p_o - p_i).$$

Now, from the definitions above:

$$\begin{aligned} p_{ia} &= p_o \\ &= p_i + (p_o - p_i). \end{aligned}$$

and

$$\begin{aligned} p_{oa} &= p_{ia} + (p_{oa} - p_{ia}) \\ &= p_o + (p_o - p_i). \end{aligned}$$

Therefore the relative radius of curvature of the tooth profile having adjusted radii of curvature

$$p_{na} = \frac{p_{oa} \cdot p_{ia}}{p_{oa} - p_{ia}}$$

therefore

$$p_{na} = \frac{[p_o+(p_o-p_i)]\,[p_i+(p_o-p_i)]}{[p_o+(p_o-p_i)]-[p_i+(p_o-p_i)]}$$

$$= \frac{p_0 p_i+(p_0+p_i)\ (p_0-p_i)+(p_0-p_i)^2}{(p_o-p_i)}$$

The increase in the relative radius of curvature $=p_{na}-p_n$

$$= \frac{p_0p_i + (p_0+p_i)(p_0-p_i) + (p_0-p_i)^2}{(p_0-p_i)} - \frac{p_0p_i}{(p_0-p_i)}$$

$$=(p_0+p_i) + (p_0-p_i)$$
$$=2\,p_0$$

The percentage increase in relative radius of curvature $= \dfrac{2\,p_0}{p_n} \times 100\%$

$$= 2\,p_0 \frac{(p_0-p_i)}{p_0p_i} \times 100\%$$

$$= \frac{2\,(p_0-p_i)}{p_i} \times 100\%$$

and, as the load carrying capacity may be considered as proportional to the relative radius of curvature, the percentage increase in load carrying capacity equals

$$\frac{2\,(p_0-p_i)}{p_i} \times 100$$

If we take by way of example a typical case where

$$\frac{p_0-p_i}{p_i} = 0.05$$

the load capacity of the gears would be increased by 10 per cent.

It is envisaged that there is a limit to this centre shift as interference may occur if it is carried too far, but by siting the centre of curvature of the concave curves on the pitch surface of the gear member having the convex teeth profiles, a significant and useful increase in the load carrying capacity of the teeth can be achieved without causing interference.

The application to the invention to a gear wheel having concave flanked teeth and engaging a complementary rack having convex faced teeth will be apparent to those skilled in the art.

Figures 4 and 5 illustrate the application of the invention to the case of a helical gear wheel engaging a ring, or internally toothed gear wheel, the radius of curvature of the convex curves, in both cases, being shown greater than the chordal thickness T of the respective teeth on which they are formed.

In Figure 4, the inside gear wheel IX is provided with convex faced helical teeth 2X, while the outside ring gear IIX is provided with concave flanked helical teeth 10X. The centre of curvature 4X of one of the convex faces of teeth 2X lies on the pitch point 13X and the centre of curvature 8X of the corresponding concave flank of one of the teeth 10X lies on the side of the pitch cylinder of wheel 11X which is remote from the roots of the teeth 10X.

In Figure 5, the inside gear wheel 1Y is provided with concave flanked helical teeth 2Y, while the outside ring gear 11Y is provided with convex faced helical teeth 10Y. The centre of curvature 4Y of one of the convex faces of teeth 10Y lies on the pitch point 13Y, and the centre of curvature 8Y of the corresponding concave flank of one of the teeth 2Y lies on the side of the pitch cylinder of wheel 1Y which is remote from the roots of the teeth 2Y.

WHAT WE CLAIM IS:

1. A helical gear set comprising complementary first and second gear members having gear teeth, the respective profiles of which are, at each transverse cross-section, convex and concave curves based on arcs of circles, wherein the centre of curvature of each convex curve at each transverse cross-section is located on the pitch surface of the first gear member, and the centre of curvature of each concave curve at each transverse cross-section is located on the side of the pitch surface of the second gear member which is remote from the roots of the teeth of the second gear member, the radius of curvature of each convex curve being not less than the chordal thickness, as herein defined, of the teeth of the first gear member.

2. A helical gear set as claimed in Claim 1, wherein one of the gear members is a gear rack and the other gear member is a helical pinion.

3. A helical gear set as claimed in Claim 1, wherein one of the gear members is a helical gear wheel and the other gear member is a helical pinion.

4. A helical gear set as claimed in Claim 3, wherein the helical gear wheel is a ring gear having internal teeth.

5. A helical gear set provided with teeth shaped substantially as shown in, and adapted to operate substantially as hereinbefore described with reference to, Figures 1 and 3, Figure 2, Figure 4 or Figure 5 of the accompanying drawings.

J. W. RIDDING,
Chartered Patent Agent,
33 Grosvenor Place,
London, S.W.1.
Agent for the Applicant.

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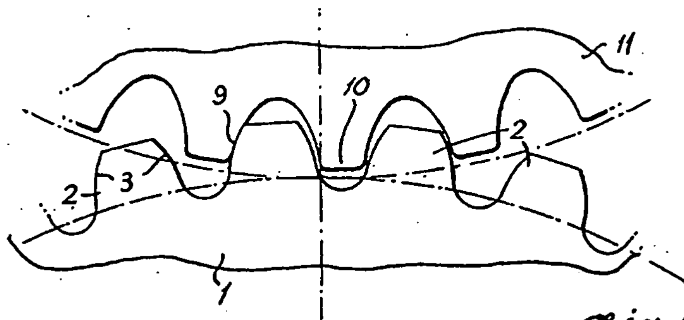


Fig.1.

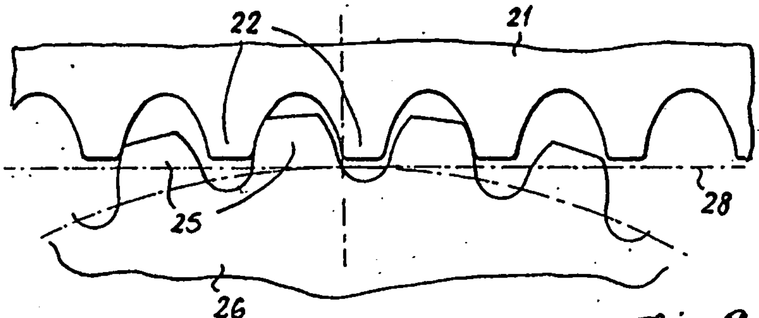


Fig.2.

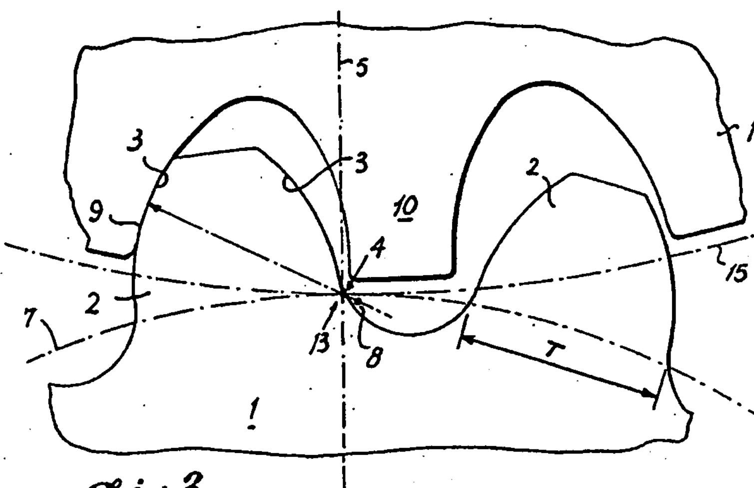


Fig.3.

1,032,095 COMPLETE SPECIFICATION
2 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2

Fig.1.

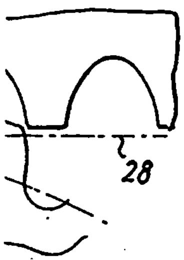


Fig.2.

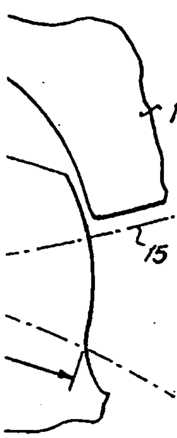


Fig.4.

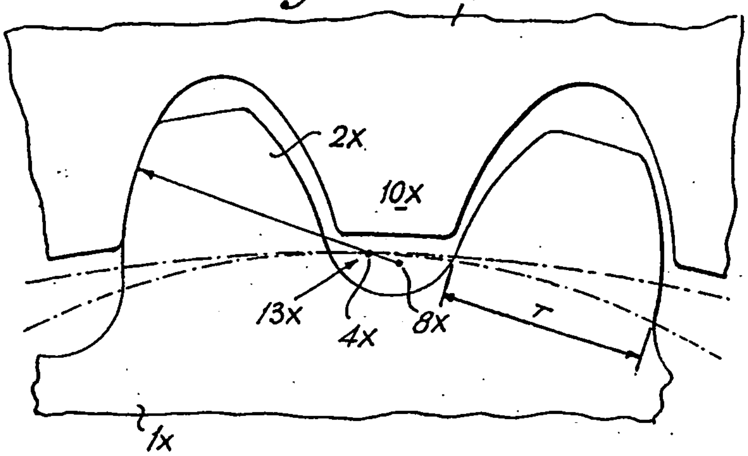
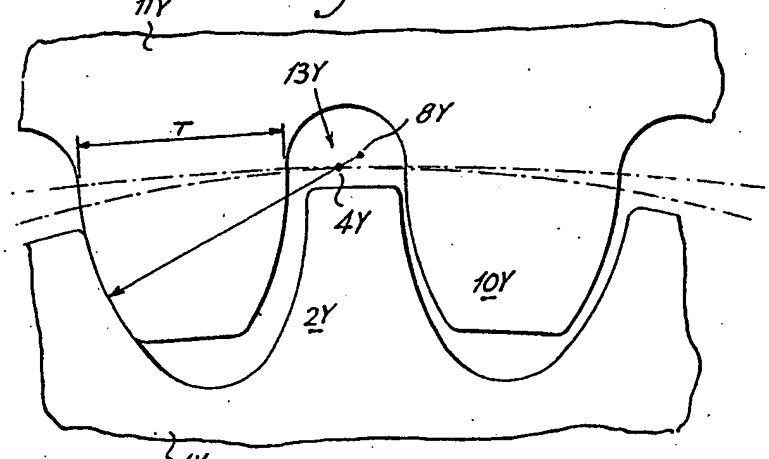


Fig.5.



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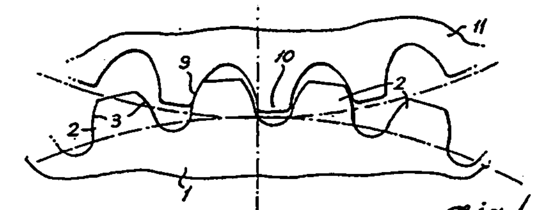

Fig.1.

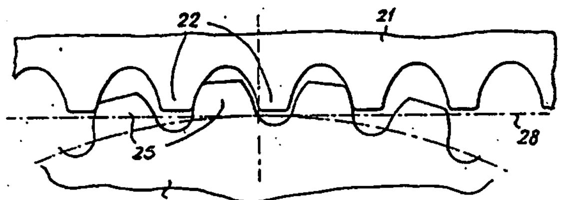

Fig.2.

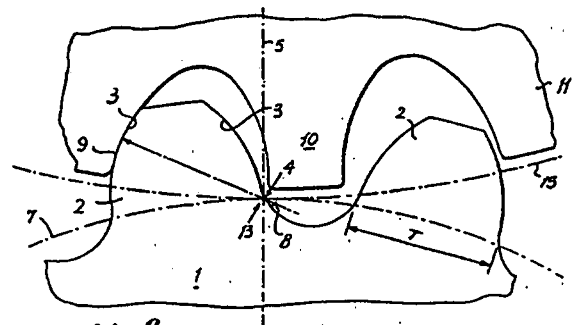

Fig.3.

Fig.4.

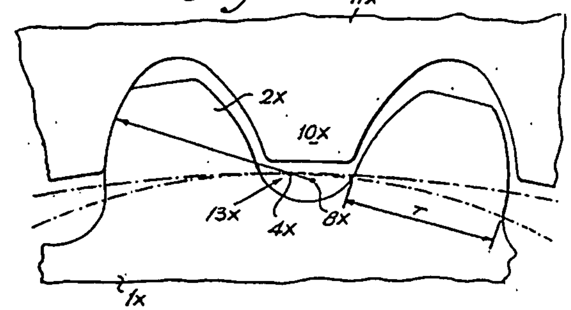

Fig.5.